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FARMING FOR FISHES

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BY

SENATOR WARREN G. MAGNUSON

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FOREWORD

The Committee on Interstate and Foreign Commerce has ordered printed a chapter from a recently published book entitled "The Sun, the Sea, and Tomorrow." The authors, Dr. F. G. Walton Smith, director of the University of Miami Marine Laboratory and Mr. Henry Chapin, research historian, have condensed in a composite report valuable information regarding our fisheries and aquatic life that is inspiring to all who read it.

The authors have given their permission to use the chapter entitled "Farming for Fishes." This chapter reveals much enlightening information on a subject for which Congress appropriates annually millions of dollars; namely, the science of fish culture. This science is more fully understood in other sections of the world and I believe that all who are interested in the future welfare of fisheries will benefit from the report by Messrs. Smith and Chapin.

WARREN G. MAGNUSON,
Chairman, Committee on Interstate and Foreign Commerce.

FARMING FOR FISHES

Introduction by Senator Warren G. Magnuson

The whole concept of Dr. Walton Smith's and Henry Chapin's analysis of the evolution of fish and marine life, and the estimated value of marine products to mankind, causes us to wonder about the progress we are making today to preserve our natural marine resources, and to speculate on successes we have made in the development of the science of fish culture in the United States.

In Alaska we have 2,000 rivers and streams grossly depleted of natural stocks of salmon, a resource from which we have taken and put nothing back. Likewise, salmon and other species of fish have long disappeared from waters along the Atlantic coast.

In the management of our natural oyster farming areas, such as Chesapeake Bay, we are still employing antiquated methods of shellfish management, which were discarded by Holland and France over 60 years ago. Under more practical management of cultural operations European production of oysters has increased many times over former years, while ours have become many times less than the stocks nature alone provided us.

Our clam beaches and tidal areas, on both the Atlantic and Pacific coasts, which comprise some of the most ideally suited in the world for the growing of clams, have become less and less populated through the years in spite of millions of dollars spent on research.

We have, through improper management, depleted our pilchard or sardine runs on the Pacific coast to the extent we are suffering an estimated annual $8 million loss in considering what might have been maintained had we not overfished the runs.

Much credit is due to those who have worked hard to preserve and improve our fresh-water and inland fisheries. Yet, here, too, private enterprise can supply commercially, stocks of fish at near half the cost of Government-produced fish for the stocking of lakes and streams. Our position has not been to encourage private enterprise in these operations.

Dr. Walton Smith and many other well-known fish culturists of our time have pointed out a path for us to follow in this field of endeavor. They have particularly stressed the need for environmental control, mineral stabilization and disease eradication in our lakes and streams and in coastal lagoon areas to aid the growing of desirable food fish and other forms of aquatic life.

By reason of the fact there appears at present to be no true course of action taken by our Government to properly secure and maintain these resources and to stabilize the commercial-fisheries industry, the 84th Congress passed what is known as the Fisheries and Wildlife Act of 1956, which provided for the reorganization of our National Services for Fish and Wildlife. The act established a national policy to strengthen and improve the fish and wildlife segments of our economy.

Yet, with all our efforts in providing congressional support for these programs, we are still wondering when someone in the Service will come forward to state "we have the answers to this important work" or to recognize the progress and success of other countries in this field of resource management.

I believe the time has come for us to take a new look at the wonderful gifts of nature that surround us and pay more attention to the wisdom and advice of such men as Dr. Walton Smith of the University of Miami, Dr. Lauren Donaldson of the University of Washington School of Fisheries, Clarence Pautzke, Washington State Game Department; Dr. Livingston Stone and David Starr Jordan of the United States Fisheries Commission, 1889; Joseph T. Barnaby, United States Fish and Wildlife Service and his Report on Karluk River Fisheries, Ruggero de Angeles of Rome, Italy, Joseph Suta of Bohemia, 1833 to 1914; Dr. Takeo Imai of Tohoku University, Sen Dai, Japan, and many others who have advocated a more practical concept in meeting our fisheries needs for the future.

THE SUN, THE SEA AND TOMORROW

By F. G. Walton Smith and Henry Chapin

Chapter 5. Farming For Fishes

Because of the untamed and elemental nature of the sea it is the last area of the globe that man has to conquer and bend to the uses of his civilization. Conquer is a poor word to use, perhaps, because it means ravage, rape, and exploit as well as intelligently dominate. The oceans have been fairly impervious to the good or ill man can administer in this ardent "conquest" of nature. *Today, we approach the sea as men 300 years ago attacked the virgin continent of America. We hunt, trap, and begin to cultivate the margins of a half-known area of vast resource.*[1] It is easy for a landsman to pose the question of why we do not apply the same energy of scientific engineering to the sea that we have learned so well to do in our agricultural advance on land. But the sea is really another world where the potential harvests are alive, on the move both vertically and horizontally, and where the farmers of the sea cannot readily build on and fence in such acreage as the Grand Banks.

Wherever the land is right for it, we can have our herds of beasts and control our pasturage and calculate the resulting food per acre. We can further improve our output by selective breeding of the creatures themselves and the provender they consume. Can this be done with the ocean herbivores, the fishes which are the flesh of the sea? Attempts have been made for a long time to do this on the fringes of the sea in many countries. At first sight it is natural to conclude that such attempts must be too trivial to count because of the extent and depth of the oceans and the untrammeled alien nature of the waters. Nevertheless, such attempts have been made with some success and benefit to mankind.

In general, three methods have been mainly followed in our effort to farm the ocean waters. In point of time the oldest practice, dating back many centuries, has been the cultivation of fishes in ponds and inlets of the sea, closed off and captive. Then, in comparatively recent times, during the 19th century artificial fertilization of eggs was tried successfully and the small fry or larvae were held in hatcheries until considered old enough to release into ocean waters with the hope that this would increase depleted natural stocks. In other places, the practice of transplanting young adult fishes from areas of abundance to areas in which the fish in question had never lived was tried in an endeavor to build completely fresh stock. In addition to this method, transplantations have been made from overcrowded environments to less crowded areas where plentiful food allowed a more rapid growth. Man is only beginning to probe the potential of such methods of development and it is well worth asking just how far we can push these practices beyond what we are doing today.

[1] Emphasis supplied.

Past studies in marine biology have emphasized the enormous reproductive possibilities possessed by most fishes and have created an intense interest in their cultivation and in the development of hatcheries and new methods of transplanting and restocking the supply of edible fishes in the sea. In the 19th century, biologists argued that natural propagation was inefficient and that man, by supplementing nature through the artificial fertilization of eggs by newly discovered methods, offered a far more efficient way of increasing natural populations than nature itself could accomplish unaided. The enthusiasm for the view is well illustrated by Bower, who wrote in 1898: "due proportion must be taken from their spawning grounds so that sufficient ova may be touched by the magic wand of protected propagation to provide for future crops."

About a hundred years ago fish culturists discovered that they could artificially fertilize fishes by stripping the milt and eggs from males and females and mixing them together under controlled conditions. By exercising reasonable precautions against changes of temperature, lack of aeration and mechanical shock, it was found that fertilized eggs and young fishes could be carefully transported over considerable distances. This set in motion a great wave of poorly planned hatching and transplantation where enthusiasm overbalanced careful scientific observation; for in most cases no adequate analysis was made of end results and it was often found, when checks were made, that there were no detectable benefits whatsoever.

But in spite of many failures several extremely successful transplantations came off, notably the transfer of shad from the east to the west coast waters of the United States. The shad is a salt-water fish of the herring family which swims up the coastal rivers in the springtime to spawn. The first attempt at releasing artificially fertilized larvae of shad was made in 1848 in the waters of the rivers entering the Gulf of Mexico, but it met with failure. Likewise, between 1873 and 1892 large numbers of these baby shad were hopefully placed in the Colorado River and even in the very saline waters of the Great Salt Lake. In these cases also the fish failed to develop or to reproduce in their new environment. But about this same time over 600,000 larvae were taken from the Hudson River and turned loose in the Sacramento River and another million released in areas north of San Francisco Bay. Here, at long last, a favorable new environment was discovered and the young shad developed so well in succeeding generations that they have spread from southern California to Alaska. This success can be measured in terms of food for man by the fact that the take of 100,000 pounds in 1888 has risen to a catch of 4 million pounds of shad today. Here, indeed, is an example of what can be done when fishes are transplanted to areas lacking such species and where the environment is perfectly suited to their specific needs.

Another Atlantic food fish transferred cross-continent to a strange ocean with signal success is the striped bass. This fish has somewhat similar habits to the shad and was completely foreign to California waters although abundant in the East all the way from Florida to the Gulf of St. Lawrence. This transfer was a natural followup of the good results with shad and in 1879 and 1882 less than 500 fish between 1 and 10 inches long were taken from New Jersey to the Pacific coast. So apt were the striped bass to these new waters that by the end of the century the descendants of the pioneer 500 were supplying commercial

fisheries with over a million pounds a year, which doubled by 1904. Today this is one of the most important game fishes of California.

This experiment, so obviously successful in itself, brings up an important problem arising from the success in transplanting a single species of fishes, namely, that there is a possibility that the striped bass may have a detrimental effect on the native Pacific salmon population. Admirable though an invasion may be in some aspects, it may still be hard on the old inhabitants. There is, of course, nothing to be gained by introducing a new species in an environment if it upsets the natural balance in competition for food or for other reasons, so that the newcomers merely replace a similar number of a more valuable native fish.

In spite of the record of success in the two transplantations just mentioned, there are few records of other such attempts succeeding, which is a good enough indication of the many complicated factors involved beyond the mere physical introduction of healthy fish into a new environment. Much closer coordinated study of saltiness and temperature, food and the natural enemies of fishes must yet be made before the practices followed with good luck in the case of shad and bass can be intelligently applied on a larger and more scientific scale. One other case, however, should be noted, namely, the transference of trout and salmon from Great Britain to New Zealand where they now live in great abundance in the rivers. But we cannot consider this a completely successful case of sea transplantation because in New Zealand the salmon remains in fresh waters and no longer takes to the sea. Why they do not duplicate their long European migration to mid-Atlantic by a similar migration into the Pacific waters is hard to explain and seems to be one of the unsolved mysteries of the instinctive actions that so much control the life of fishes in general.

Transplantation by man is used in another fashion than that of seeking a totally new environment for a species. This is when fishes are taken in quantity from an unsuitable or overcrowded neighborhood and placed in one that is less crowded—a sort of slum clearance, in fact, aimed at better living conditions. This interesting work has been carried out successfully on a large scale in European waters with plaice by the Danes. The plaice is a bottom-living flatfish which lays its eggs during the winter in the warmer waters of the North Sea. As these eggs develop into young fish they drift toward the coasts of Holland and Denmark. From the Danish seacoast a narrow channel connects the North Sea with an extensive system of sheltered waters called the Limfjord. In the western neck of this semienclosed system of waters there are large numbers of plaice but they remain small in size. They have migrated here from the open North Sea but because of overcrowding there is too much competition for food and they do not develop well. Some few of these Limfjord plaice penetrate, however, through the inland waters and reach broad inner eastern reaches of the fiord and these few grow more rapidly and to greater size. But the fish do not breed in this better inside environment. So, a trial was attempted to make use of the superior feeding grounds by transplanting small plaice from the overcrowded western end of the fiord to the eastern end where they could find more room and better food. The first experiment was made in 1892 with some 80,000 fish. Many of them were tagged for observation and when recaught it was found that these fish, less than 10 inches in length originally and weighing

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less than a quarter of a pound, had increased as much as 5 times their weight during a period of 6 months after transplantation. Since 1908 between 1 and 3 million plaice have been transplanted each year, except when the project was interrupted by war. This scheme, technically so successful, has also been commercially a boon to the Danes as the value of the increased catch has been more than five times the cost of the effort.

The North Sea, which has been heavily fished for centuries by the Scandinavian countries, England, and Holland, may truly be said to be one of the few seas that have been overfished. The most striking area where this has occurred is in the Belt Sea plaice fisheries surrounding the Danish islands of Seeland and Fiinen. But here again man stepped in to remedy shortages he himself had created, by bringing to the Belt from 1 to 2 million plaice each year from Horn's Reef, an overcrowded area of undersized fish. This experiment has been most successful, except of course for the interruption of World War II. It is interesting to note that the plaice transferred from the North Sea to the Belt are of a slightly different race and when liberated in the Belt Sea grow at a much greater rate than the local race of fish.

Other transplantations similar to the Danish experiments but on a small scale have been made in European waters. This shows that man can do much to augment his food supply from the sea when he is aware of the natural conditions at hand and aims to cooperate with nature rather than to make a blind stab at a bonanza result which may fail or even adversely affect the delicate biological balance. It has been demonstrated, for instance, that it is economically sound to transplant young plaice from the overpopulated English and Danish inshore areas to the Dogger Bank, in the North Sea, to which the young plaice are prevented from migrating by the intervention of deep waters. On the Dogger Bank they grow about four times as rapidly as they do in their original location. Calculations have shown that there are, crowded in the Horn's Reef area, well over 100 million young, undersized plaice at the age and growth appropriate to transplantation. Moving a large proportion of these would benefit rather than harm the fishing in that locality.

Actual experience makes it clear, then, that transplantation under favorable conditions can be both biologically and economically successful in establishing a new fishery or in bringing about a healthy increase in production in a fishery long established. It has also been well demonstrated by experience, and by the large numbers of unsuccessful transplantations due to unfavorable environment and the competition set up between new stocks and endemic or native stocks, that there are sufficient reasons to go slow. So, if man is going to join the dance, he had better know the steps; in other words, before rushing hopefully into new projects, careful scientific study is imperative.

Scientists being human are not immune to enthusiasms and fads, and scientific opinion tends to move in cycles, first pushing one theory and then another. The realization in mid-19th century that our fisheries were not inexhaustible or limitless led to overstress of the role of fish hatcheries as an answer and brought them into fashion. There was a great wave of attempts to restock the sea fisheries with larvae

and small fry artificially hatched by man.[2] In the United States, Great Britain and Norway, in particular, the hatching of marine food fishes was carried out on a large scale but with results that are now considered to be of questionable value, if not demonstrably worthless.

Take as an example the large shad hatcheries of the United States which have released as many as 400 million fry in a single year and yet have failed to prevent a decline of the fishery. Little has been done to study the effects of this kind of restocking in any detail except in Europe. One of the few careful measures of the effectiveness of hatching was made in Scotland at the beginning of the century. More than 142 million young plaice were released from hatcheries into Loch Fyne each year. Then the yearly effect of this addition upon the numbers of commercial-size plaice in the loch was measured by comparing the catch of years when fry were added, with the catch of years when they were not added. The result showed, naturally enough, an increase in the young fry because of their release but bore little relation to the size of the commercial catch, as some of the heaviest releases of fry coincided with a poor catch of grown fish. It is therefore apparent that the large fluctuations which naturally occur in sea fish stocks are substantially greater than the effects of hatchery operations. Only in a year when an additional 50 million fry were released in Loch Fyne, equivalent to 10 percent of the eggs naturally produced, did the fry release make a really appreciable difference to the catch. Similar experiments in Norway have tended to confirm the results at Loch Fyne. For instance, in 1904 when 33 million cod fry were released in one fiord the young cod were found there in unusual abundance the following autumn. But, unfortunately, so were they found in abundance in other fiords where no fry had been released. Due to another natural fluctuation of supply in 1905 all the fiords were low in codfish whether they had received artificial help from the hatcheries or not.

This does not rule out the hatcheries as aids to nature. More recent experiments tend to show that under special conditions the hatchery technique of stimulating production may be used to increase the natural yield of the fisheries or, at least, to counteract disastrous effects of natural fluctuations upon the fishing industry in bad years. Whether the costs of maintaining this type of fish farming can be economically justified is another matter. In Norway an ingenious technique was used by Rollefson for accurately checking results. He used easily recognized hybrids or crossbreed plaice in his hatchery experiments, a sort of built-in biological tagging device. After release, these fish could quite readily be distinguished from the fish naturally reproduced, when sample catches were made. The tally was somewhat similar to the Loch Fyne experiments and showed that the release of fry does increase the subsequent catch of young fish but not enough to counteract the effects of naturally caused fluctuations which were even greater.

[2] Magnuson: The merits of fish hatcheries and the culture of marine species of food fish is debatable, many scientists including the authors have indicated the productiveness of marine culture may far exceed equal areas of land culture in the production of food under ideal conditions. Nature has indicated often the possibilities of high yields of food fish where conditions have been favorable. (See appendix fig. 2.)

TABLE I

	Number of hybrids released (in millions)	Percentage in the Catch	Ratio
1935	2	1.5	0.75
1939	7	40.0	5.79
1937	7	0.5	0.07
1938	10	96.0	9.6
1936	13	30.0	2.3

From this brief résumé of some of the trial and error experimentation done so far, it is evident that we are still only in the early stages of using fish culture or transplantation as a practical way of increasing the supply of available protein from our open sea fisheries. There is no question but that considerably more knowledge is needed regarding the causes of natural fluctuations in native fish stocks before hatchery techniques can be satisfactorily used. It is clear that merely to add newly hatched fry is rarely likely to be of value and that even the release of partially mature fish may never be very useful except in restricted locations such as the Scottish or Norwegian lochs and fiords. Millions of fry coming from the hatcheries seem like a great quantity until we compare them to the natural productivity of the fishes involved. A single female, cod, for instance, produces from 1 to 5 million eggs a year. A hatchery rarely produces more than 200 million fry a year, which after all is about the equivalent of a few female cod at work on their own without benefit of man and an expensive overhead. The lesson is simply this, that man can step into the natural cycle of production and increase results to a useful level only when he has the data and the experience to augment intelligently long-established natural processes. Man's best luck has come, as with the shad, where he has been fortunate enough to find a virgin area with an optimum environment for a transplanted species to flourish.

And this leads to a point that may someday bring further good results, namely the artificial removal by man of predatory or less valuable fish from an area, thus releasing food supply in the sea for the expansion of useful species or for the introduction of a new species in the vacancy in the food chain thus created. As a plausible instance, we might cite the benefit to shrimp of a possible removal of red snapper from Gulf of Mexico waters since the red snapper takes 10 times its own weight in shrimp as food. Here shrimp is the more valuable seafood and has the further advantage of being a direct feeder on plankton, which is at the base of the sea's natural food scale. The same conjecture would hold if menhaden, which are not edible, although they also are direct plankton feeders, could be replaced by herring which are plankton feeders but are one of man's most useful food fish and likewise, in surplus, could also supply oil and fish meal. At present, of course, we have no practical way of interfering with the food chain except by the purposeful overfishing of the less desirable types, but this does not preclude the future development of such techniques.

The proponents of sea hatcheries admit that the success of their releases of fry depends upon natural conditions in the sea after release. But conditions thus favorable to hatchery fry are also favorable to naturally produced fish. What is really needed is a method of

artificially providing more fish under unfavorable conditions. Only a small part of the eggs released in nature ever attain full growth into adult fish, and it is therefore essential that the hatcheries rear their young fish beyond the stage at which the greatest mortality occurs in nature. As yet, the biological and hydrographic conditions which prevent the majority of eggs becoming adults are not too well understood, but it appears that the greatest loss in nature occurs just after the young fry has consumed all its egg yolk and is beginning to forage for itself. The fact that fish are usually liberated from sea hatcheries at this most critical stage of their lives is undoubtedly one of the present serious barriers to their usefulness.

As an aid to getting the larvae past the difficult period when they are learning to feed for themselves, some recent experiments have been made in supplying young plaice fry with plankton food which they can use. If this technique can be developed without greatly increasing the cost and difficulty of fish culture, then a great new era of usefulness may develop for the hatcheries. Another encouraging advance is the ability to predict poor fishing years ahead of time by sampling the stock of all ages and year classes. Year classes, that is the fry of any given year, vary greatly in numbers, due to their hard fight for survival, and thus can act as indicators of the numbers of marketable fish which will be available as these various classes mature. So, by releasing larval fish at an old enough stage to insure survival and in the right years, it might be possible to counteract poor years in natural production and to level out the natural fluctuations of members.

What we have just pointed out about fish hatcheries also applies in a large measure to lobster hatcheries. A great deal of Government money has been spent in raising small lobsters and then releasing them into the ocean without any evidence to show that this is anyway benefits the fishery. Here is another example of how much the value of artificial propagation has been overemphasized in past years while at the same time the efficiency of natural reproduction has been underestimated.[3] In a like degree, the fresh-water hatcheries, which were the original starting point for this fashion, are still biologically unsound operations. Their actual value of conservation is nil. The planting of fingerling trout in streams is a waste of public funds since the return to the angler does not even reach 1 percent. It has been shown, for instance, that in Michigan streams more young are naturally produced than the waters and available food can support.

On the other hand, the rearing of fish to a legal size old enough to briefly fend for themselves, is a most expensive operation. Far from being good fishery management or conservation, it is no more justified biologically than if the anglers were to catch them directly from the hatchery ponds. It remains, however, the only means of satisfying many amateur pioneers with rods and a license, and a vote. In the case of sea fisheries, it would be even more expensive to raise adult fishes or lobsters and certainly foolish to release them into the open sea rather than directly into market baskets.

A problem still to be considered which may need the application of the best hatchery techniques merely to survive, is that of our extensive salmon fisheries. The salmon is not only an ocean fish caught at the

[3] Magnuson: It should be noted that recently the Washington State Game Department and several other conservation agencies have introduced wide-scale lake poisoning programs that has increased the survival of hatchery planted fry by 1,000 percent. (See appendix fig. 1.)

entrance to rivers as well as at sea but is one that has to seek the upper reaches of fresh-water streams to breed. Therefore, man added extra hazards to its existence when he brought in dams, hydroelectric projects and the chemical pollution of the streams by factories. The heavy exploitation of the salmon fisheries has already commenced its decline. Successful salmon hatchery operation, as well as more extended construction of fish ladders and bypasses for spawning salmon ascending the rivers, is badly needed to counteract man's interferences with the natural cycle of the salmon's life.

So it is not hard to see that whatever we have done in artificial propagation or transplanting of young fish falls far short of the full control needed or of the control that a farmer has, for instance, over his fields and his cattle. The released fry or transplanted fish have for the most part to be let loose without restraint so that their capture and use by man depends once more on the old hunting techniques. But there is a closer approach to our land control of food animals in the practice of pond culture of fishes in which they are restricted to comparatively small bodies of water and are fed and cared for to the point where they are as domesticated as cattle.

The greater portion of fishpond culture is carried out in fresh-water lakes or ponds. But the pond culture of salt-water or brackish-water fishes is widespread among the less industrialized people of the Far East, in the Philippines, Indonesia, India, and China. This art has been developed for at least 500 years in Java, where today over 15 percent of all the protein in the diet comes from fishponds. It is legendary in Hawaii that there were extensive pond-culture fisheries at Pearl Harbor 300 years ago. In spite of this antiquity and the undoubted value of pond fisheries as a supply of food, only in recent years has western man begun to make any serious study of it. In the East today the fishpond culture is carried on for the most part by oldtime rule-of-thumb methods without regard to scientific knowledge.

In Batavia, Singapore and Formosa most of the salt-water ponds are simply fish traps with gates which allow the fish to enter at high tide. Once caught they are held to grow and fatten in the ponds. The great disadvantage of this method, of course, is the lack of selection which permits the enemies and predators of useful food fishes to be trapped along with them and so keeps the final yield unnecessarily low. In recent years an advance in this practice has been made by catching the young fry from the sea and releasing them in specially prepared ponds free of hostile fishes.

Where the deep-sea fishing has not been developed and the pressure of a poor and hungry population has long existed, such as in the Philippines and Indonesia, great use has been made of the pond culture of the bango or milkfish. In the Philippine Islands alone, an industry involving a capital outlay of $150 million provides about 17 million pounds of fish annually. This is particularly true for the Manila area where the bango is the principal protein food. After hundreds of years of slow development, pond culture here has reached the stage where it precludes predatory fishes and goes beyond that to ensure the correct type of food for the milkfish at various stages of its growth. No fertilizer is added to these ponds but there is probably a good deal of natural drainage which helps to feed the native aquatic vegetable growth. Every few years most ponds are drained and the bottom silt is plowed and turned over, thus stirring up sediments which prob-

ably add to their fertility. Philippine milkfish spawn offshore from the sandy coasts and then the young fry move inshore where they can be readily captured. They are first put into ponds where a bottom growth of blue-green algae provides a natural food. After they are about 3 inches long the young fish are transferred to ponds with a different growth of green filamentous seaweed appropriate to this stage. Sometimes the fish are transferred again before finally reaching marketable age. The care of the fish during the different stages of growth is frequently handled by men skilled as specialists in the different phases of pond culture.

Once again pond culture illustrates the advantage of the immediate transfer of vegetable food into protein without the intermediate steps from grazing fish, to small carnivorous fish, to larger fish until suitable for commercial use. There is a minimum loss of energy in the process of conversion from one stage of the food chain to another instead of an increasing loss through several successive conversions. Let's look at it this way. One thousand tons of vegetable plankton converted by grazing to animal plankton, then to plankton-feeding fishes, and finally to carnivorous fishes will in the end only supply 1 ton of fish; then compare the fact that this same 1,000 tons of vegetable algae in the salt ponds, when converted directly as food to the milkfish, will yield about 100 tons of fish. Here by shortcutting the chain of conversion, man arrives at a hundred times better production of protein food.

Many thousands of miles of low-lying coastal swamp country in the tropics and subtropics, not at present under pond culture, would make favorable areas for an extension of fish farming from a purely biological point of view. *In many ways the yield of food is better than that of direct agricultural land production. In China, for instance, pond culture is said to yield as much as 5,000 to 7,000 pounds of fish flesh per acre, compared to 800 pounds per acre for beef on the best grazing lands.*

But there are good reasons why a greater use of this form of food production has not greatly increased in many years. In the first place, science has only made a beginning in the study of pond cultures. These have survived on a trial-and-error, empirical basis depending on local necessity, namely, dense human populations with a low standard of living. This creates the cheap labor required in pond upkeep and also no doubt furnishes, through natural drainage, a considerable supply of human fertilizer. All the factors—economic, social, and particularly biological—need joint study before the potentially suitable areas around the seacoasts of the world can successfully be added to present production. There is no use having a good source of food so far removed from a concentrated market that it is economically impossible to use it. And further, in spite of a possible great increase in pond culture, this type of production still would only be a relatively small fraction of the full ocean food potential.

Before leaving this subject of fish farms we should look at the story of oyster cultivation which is one of man's most successful attempts to control salt-water food supply. This culture, like that of fishponds, is of ancient origin. Two thousand years ago the Romans at Brundusium collected oysters and transplanted them to the Lucrine area to protect them from storms, and even erected buildings along the shore to break the force of the winds. The growing oysters were attached to ropes which hung in the water between stakes while they were fattening.

This has a parallel modern practice and, as a matter of fact, Dr. Costé of France, who saved the French oyster industry almost singlehanded by his investigations in the late 19th century, started his studies with the traditional Italian methods.

Today, oysters are cultivated all over the world where conditions are favorable, in Australia, Japan, the United States, France, England, Holland, and as far north as Norway. The methods differ in detail but on the whole are necessarily dictated by the peculiarities of the oyster's way of life. These are interesting because they well illustrate the conditions of prolific breeding and tremendous destruction of young life that is common to the cycle of growth of many sea creatures. Because oysters grow in shallow waters, man has been able to study their life cycle in great detail. They live out their adult life in fixed positions and are susceptible to easy handling and transplanting by man.

Essentially the oyster is a pump, a sort of submarine vacuum cleaner and a single small shellfish can pass as much as a hundred gallons of water a day through its system sorting out the minute plankton and algae it needs for food and rejecting the debris. It is evident that the type and purity of the water the oysters live in is of the utmost importance. So likewise is the salinity and temperature of the water. Oysters must have an admixture of fresh water with the salt and they therefore thrive in estuaries. This reduced salinity tends to protect them as well from the drills and starfish which are among their greatest enemies. Though quiet, conservative and fixed in his habits when grown, the young oyster has an adventurous, rough life. It survives not necessarily because it is the fittest but by the pure hazard of where it finds itself at the end of a helpless initial period of drifting in the waters. We must fumble in describing the sex of the oyster as it is a strange creature which usually starts as a male in the first breeding season and then alternates male and female thereafter. The fertilized eggs drift as part of the plankton for 2 to 3 weeks. One oyster produces several million young of which only a comparatively few ever survive to maturity. From a purely statistical point of view, if this prodigious mortality did not occur, the progeny of only 2 or 3 dozen oysters would within a short time be sufficient to feed the entire world population.

From the plankton stage the small spat settle to the bottom and unless they find a clean bottom where they can attach themselves to rock or sand they perish from silt, overcrowding, pollution and other natural enemies to their development. This is the most critical phase of their existence and the point where many by artificial means can best promote their growth. At that, a scant few find this suitable bottom and not many among this residue ever live to maturity. About the only self-preserving instinct an oyster has is a tendency for the young spat to seek, to some extent, their own kind. They flourish better in colonies.

Dr. Costé first introduced modern practices of conservation in western oyster culture at Arcachon in France. Here in a great shallow bay the oyster larvae are collected in enormous quantities on curved roofing tiles which have first been coated with lime and sand. After the spat attached to the tiles have been allowed sufficient time to make their preliminary growth, they are broken off by simply flaking

away the lime coating and are then placed in special trays covered with wire netting and supported above the bottom on legs. The young oyster is thus protected from silt, parasites, and overcrowding. Later on, as the oysters grow, they are placed in special fattening beds. In France, at Marennes and elsewhere, there are ponds known as claires where the oysters are fattened. These enclosed bodies of water are open to the sea only at the time of the spring tides. In the summer they warm up, become salty, and produce a heavy growth of plankton upon which the young oysters feed.

Before the culture at Arcachon was developed, the natural oyster-beds of France were threatened with extinction due to overfishing. The success of the artificial culture may be gaged by the fact that the landlocked Bay of Arcachon covering 37,000 acres produces 500 million oysters each year. The Japanese practice a similar type of oyster farming but there the young spat are collected on bamboo twigs which are placed in the spawning grounds and later the young oysters are transferred to trays and floated free of the silty bottom. Man has in this way made the oyster farming independent of suitable types of bottom.

Oyster culture in the United States has not developed the careful techniques used in Europe and in Japan. Here the old hunting culture persists and many of the oysters are produced in public waters where the methods of dredging, rather than the culture, are paramount. *The need for developing cultivation practices in oyster farming in the United States is well illustrated by the fact that even though the majority of oysterbeds are on public bottoms, nevertheless, over 60 percent of the production comes from the smaller privately cultivated areas. A vastly greater production could be brought about if good practices of cultivation were more general.* Indeed, with the large mechanical dredgers and harvesters now in use in the United States, an expanded and more elaborate system of cultivation could probably give us three times the present yield. *Let us take Holland as an example. Between the years 1840 and 1870 the public bottoms raised anywhere from half a million to 2 million oysters each year and these were poor in size or shape. After that country established a supervised and intensive cultivation of these same areas, the production was raised to 30 or 40 million oysters a year—and of superior quality.*

The reason for going into some detail on oyster culture is the obvious fact that, along with fish farming in ponds, it illustrates one of the best ways of increasing and utilizing the tremendous initial productivity of the sea. *Oysters, because they feed on plantlife and the vegetable detritus of shallow waters, are at the very bottom of the food chain of the sea and can therefore use the ocean productivity almost at full. This holds true for other mollusks such as the mussel which is reported to produce as much as 6,000 pounds to the acre where cultivated in Holland.* This may be compared to the highest production of free-swimming fish which, at the best, in such places as the Sea of Azov yields only 40 to 70 pounds per acre per year. *It is plain that man will obtain protein from the sea with least waste of energy when he is able to harvest it at the lower end of the food chain.*

As we survey the past efforts of man to enhance the natural end product of nature in the seas—that is, the supply of protein for his table—the original thesis of the necessity of changing the rather blind

instinctive hunting economy into the controlled practices and techniques of a sea-farming economy is evident. It is also evident that increasing our engineering skills is not enough unless the basic biological understanding is likewise developed. *Practices used in pond culture and oyster culture, where man abets nature in producing from the primary end of the food chain with the least loss of energy, certainly encourage optimism though there are limitations of space.*

Today, with modern methods of transport such as the airplane, and modern methods of cooling and refrigeration, the transplantation of fry and even larger fish has been greatly improved. But we have learned from earlier haphazard experimentation that it does no good to glut overpopulated areas or hopefully to populate areas barren of food or where other factors of environment, such as temperature or salinity, are unfavorable. Further, we must avoid situations where transplanted fishes will only multiply at the expense of more valuable native species or even where they may bring with them damaging parasites or new diseases. In a word, man cannot upset established biological balance in an area without risking unforeseen and dangerous consequences. The naive transplanting of rabbits to Australia is a case in point. All this points to the need of greatly increased biological and hydrographic studies. At the present moment such studies are urgently called for, both in the salmon industry of the Pacific coast, and to further our sparse knowledge of unexploited coastal waters in the tropics and the Southern Hemisphere.

Although once man thought he could automatically increase the fish populations by the mere transplanting of fry, at the present moment it is difficult to estimate what new sources transplantation may open in the future. It is reasonable to expect that this method, though it hasd ha occasional spectacular results, will not make too great a change relative to our total production from the salt ocean. Limited transplantations from nursery grounds to fattening grounds, as in the case of the North Sea plaice, have been undoubtedly valuable, but such transplantations are more or less limited to shallow coastal areas and will only serve to make an insignificant increase in relation to the total world production.

Hatching will have greater value as we are better able to raise the young fry beyond the critical stage at which they lose their egg sacks and begin to forage for themselves. But even here, successful practice will probably be restricted to semienclosed and protected waters such as fiords and lochs.

The importance of salt-water fish ponds and the supervised culture of oysters and shellfish lies in the fact that they are primary consumers of plankton and algae. But here again, as we have shown, the areas susceptible to such development are limited both geographically by the nature of coastal waters and by the ready availability of labor and a market. *The Continental Shelves are most extensive in the Northern Hemisphere and constitute only 7½ percent of our seas and oceans. The fringing coastal areas, sufficiently shallow and otherwise suitable for pond culture and shellfishes, are again only a small proportion of these Continental Shelves. Even so, with our present knowledge of oyster, mussel and clam production, it is probable we could at least treble the 4 percent of our total fish consumption which they now represent.*

It is obvious from this review of the situation that this type of study, and subsequent beneficial increase in protein from fishlife in the sea, is attacked with a great initial advantage at the beginning of the food chain which starts with the vegetable and animal plankton that appears everywhere in the vast pastures of the ocean. It is reasonable, then, to look to the cultivation and the farming of sea plants, seaweeds and the plankton as the most efficient way of extracting a maximum yield of food from salt water. This is an inquiry in itself and will, therefore, follow as the principal subject of discussion in our next chapter.

APPENDIX

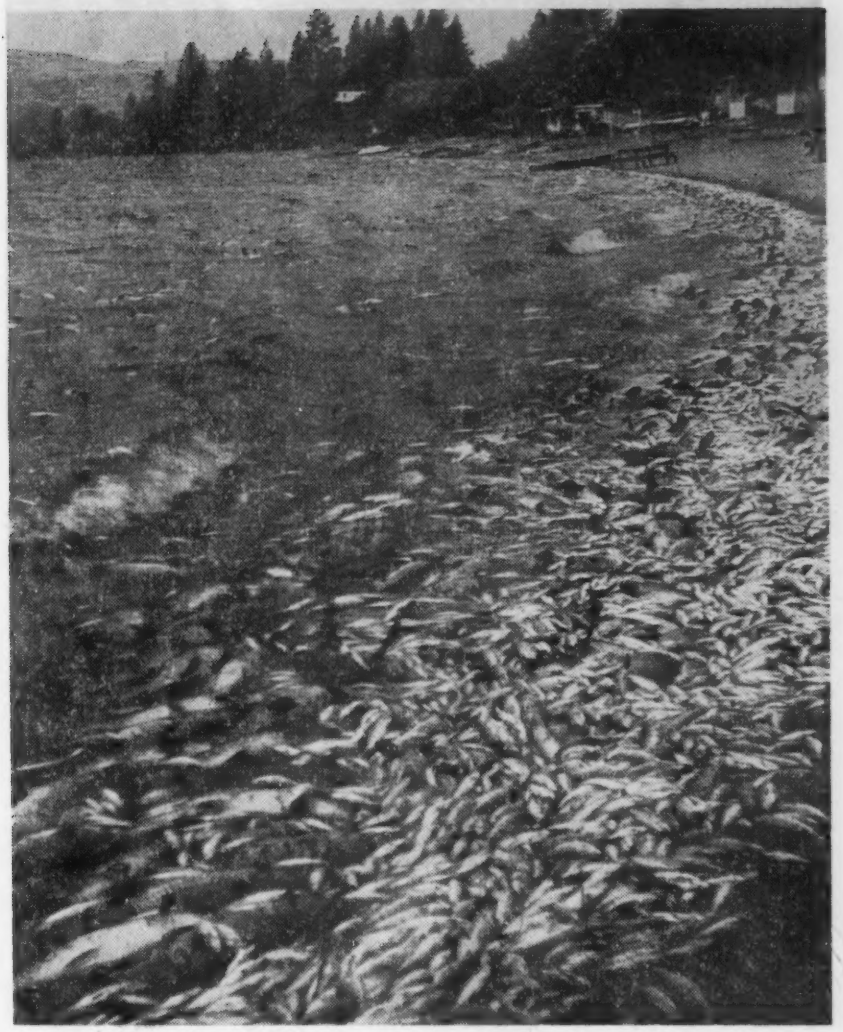

FIGURE 1. A lakeshore littered with scrap and predator fish in Washington State 12 hours after poisoning out by Washington State Game Department. After restocking the survival of desirable fish increased 1,000 percent.

FIGURE 2. Hybrid rainbow trout produced by selective breeding by Dr. Lauren R. Donaldson, University of Washington, over a period of 27 years. This new strain matures in 2 years in fresh water, the natural stocks in 3, attains an average weight of 10 pounds in 2 years compared with 2 pounds in wild fish. Will produce up to five times as much spawn for reproduction. Principles applied in this instance can be applied to salmon.